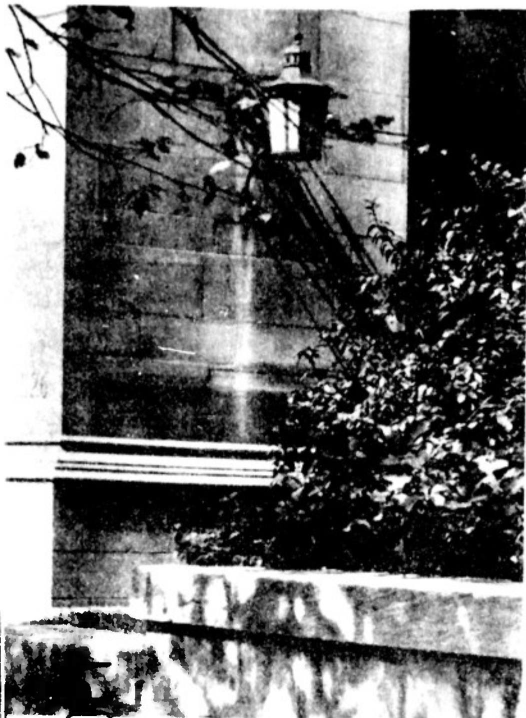

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MECHANICAL APTITUDE III

ANALYSIS OF GROUP TESTS

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ANALYSIS OF GROUP TESTS OF MECHANICAL APTITUDE

This report ~~will~~ describe and summarize the findings in the factor analysis of thirty-two group tests of mechanical aptitude. This study was started in October, 1946 under a contract with The University of Chicago and the Bureau of Naval Research. The object of the study was to isolate, if possible, some of the components of ability in the complex known as mechanical aptitude. The complete study includes several sections, namely, the construction, administration, and analysis of a set of group tests and a set of individual tests; the analysis of a battery of tests composed of both group tests and individual tests; and the comparison of high and low groups in mechanical interest and experience. It is the analysis of the group tests that will be reported here.

The first year of the study was spent on the construction and administration of a battery of group tests. Some of the tests were assembled from materials which had been used in the Psychometric Laboratory, some were adapted from tests already in use by the Navy, and several new tests were constructed to test psychological hypotheses about the nature of mechanical aptitude.

It is a matter of very general observation that mechanical aptitude represents abilities that are often distinctly different from the verbal and memorizing abilities that characterize most school work. It is often found in individuals who have academic and verbal abilities, but there are frequent exceptions. Many individuals of good attainment along academic and verbal lines are pathetically deficient in mechanical comprehension. Other frequent cases are those who show superior abilities in mechanical aptitude and who are deficient in academic and verbal intelligence. It was the purpose of this study to identify, if possible, one or more primary mental abilities that characterize mechanical aptitude. Since the abilities in this domain are responsible for the principal characteristics of our culture, it is a problem of self-evident importance to identify the psychological nature of these abilities.

We started this study with certain preconceptions concerning mechanical aptitude. These preconceptions served as a tentative guide in designing our experiments in this field. At the very start we make the assumption that mechanical aptitude is mostly in the head. It is not uncommon for the verbally minded people who are largely in control of our educational system to regard mechanical aptitude as little more than some form of finger dexterity which is associated, perhaps, with a willingness to get one's hands dirty. We believe that this conception of mechanical aptitude is entirely erroneous. The present experiments were set up in the belief that mechanical aptitude is a complex of intellectual abilities. It is assumed here that mechanical aptitude consists of an unknown number of primary abilities. The present study is an attempt to identify one or more of them. It is sometimes claimed that mechanical aptitude is defined by experience, interest, and motivation. It has seemed to us that mechanical and electrical experience, derived interest in these types of activity, and motivation to excel in them make a very important contribution to the development of actual skills and good performance along these lines. But we seriously doubt whether this is an adequate explanation for the fact that some children take readily to these types of activity at an early age, whereas others shun them and seek self-expression in other ways.

As a further guide in setting up these experiments, a number of additional hypotheses concerning the possible nature of this complex were made. These hypotheses will be described briefly.

Among the primary abilities that have been identified so far, it seems plausible that the space factor S should be the most closely associated with mechanical aptitude. In the analysis of previous factorial studies it has seemed evident that, although the space factor is very clearly defined so that its presence or absence in a new test can be predicted with some confidence, this factor does not represent adequately the individual differences of mechanical aptitude. Observations in different ways have seemed to support the hypothesis that those who have mechanical aptitude excel in the ability to visualize space in two and three dimensions, but that the space factor S, as we have known it so far, is probably only one component in this domain. Therefore, it has been a psychological problem of considerable interest to identify, if possible, the additional space factor that may be represented in thinking about three-dimensional space. The question has also been raised whether the factor which Guilford has called "visualization" is one of the factors that we are looking for. If so, it should be necessary to find the psychological nature of that factor and its psychological differentiation from the older space factor S.

Another hypothesis in terms of which some of the present test battery was assembled is that mechanical aptitude requires the visualizing of movement in space. It is conceivable that there is a functional differentiation between the ability to visualize solid objects when they are stationary, and the ability to visualize solid objects when they move in space. Such a psychological hypothesis would seem the more plausible when we consider that a mechanical device in action usually implies movement. Even the design of static structures implies movement of deformation under load.

In considering the psychological problems that are concerned with the visualizing of objects moving in space, one naturally raises the question to what extent this type of thinking is mediated by truly visual imagery and the extent to which it is mediated by kinesthetic imagery. It would not be surprizing, therefore, to find separate visual and kinesthetic imagery factors in this domain. In the same context we should consider the possible separate existence of factors that mediate bodily orientation to the surroundings, and visualizing of objects in space without reference to bodily orientation. These are only psychological possibilities to be kept in mind in designing the tests which might be crucially differentiating among such primary factors if they exist. It would then be conceivable, for example, that an airplane pilot would excel in the type of thinking where bodily orientation to the surroundings is an essential element. He might not excel in problems requiring visualizing of complex spatial relations independently of bodily orientation to them. There is also the possibility that this distinction is nothing but an artifact of our own construction.

It is conceivable that the ability to visualize an object as it moves in space in relation to us is not the same as the ability to visualize the mutual displacement of parts of a configuration that we are thinking about.. This question will be discussed again in the interpretation of some of the findings.

In the early multiple factor studies of primary abilities we had in mind a possible distinction between the ability to visualize flat space and the ability to visualize solid space. In our first factorial study[1] we failed to discover any such differentiation. It now looks as if the situation is a little more complicated than we first thought.

The considerations that we have described briefly might lead to differentiation in the ability to handle problems in solid geometry and in plane geometry, and to different abilities in kinematics and in descriptive geometry. In general, we find that in this study, as in previous studies, the differentiation among the primary abilities cannot be made dependably along the lines of logical classification of external objects. It seems to be more fruitful to identify the primary abilities in terms of the kinds of psychological functions that they represent rather than in terms of overt adjustment to external objects.

Another tentative hypothesis is that mechanical aptitude includes one or more factors concerned with speed of perception. This hypothesis does not imply that those who excel in solving mechanical problems are fast workers, but that they may excel in some perceptual qualities which are distinct from the abilities to visualize static or moving objects.

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[1] L. L. Thurstone, Psychometric Monograph No. 1, Primary Mental Abilities (Chicago: University of Chicago Press, 1938).

Another hypothesis is that mechanical aptitude includes visual memory. Such memory may be particularized in visual memory for form if there should be several factors in the restricted domain of visual memory. Several of the group tests were designed with such a hypothesis specifically in mind. In this case we are not so much concerned with speed of perception in general, but rather with the ability to keep in mind a visual detail, even with the distraction of other visually presented forms. In designing tests in the attempt to isolate such a factor, special care has been taken to avoid, or at least to minimize, the complications of verbalization. It is our impression that aptitude in this area is definitely not characterized by verbal imagery. There might even be some interesting kind of contrast between facility with verbal imagery and the kind of reasoning that is called for in solving mechanical problems. The tests for this hypothesis were therefore designed so that visual memory for form, if there is such a factor, would be revealed in superior performance even though the tests were specially designed so as to minimize the translation of the visual task into some verbal equivalent. If visual forms were used that could easily be verbalized, then the results might be confusing. We should not know whether the superior performance was due to the function of some kind of visual memory for form or to facility in translating a visual task into equivalent verbal terms. This problem of translating a presented task from one medium to another for purposes of recall or intellectual manipulation is itself a fundamental psychological problem that should be separately investigated.

A general principle that has been adopted for this study concerns the use of practical tests of identification of tools. For practical purposes, it may be useful to identify boys with mechanical aptitude by merely determining whether they are familiar with hand tools and perhaps with machine tools. If they already know what these instruments are called and what they are used for, then one can make the practical inference that they have an interest in mechanical things and that perhaps they also have some ability in that field.

The solution of the scientific problem in the present study will not be successful unless we can find some components of mechanical aptitude which can be identified in terms of the psychological processes involved. Such a description must be independent of tests which merely ascertain that the subject has learned the names of hand tools and where they are to be used. To the extent that we fail to identify the fundamental components in mechanical aptitude, we may find it necessary to resort to practical tests in which we merely ascertain whether a boy has been sufficiently interested in mechanical things to become acquainted with the tools, their names, and customary uses.

In designing the experimental tests for this study we have been guided not only by a number of tentative hypotheses, but we have also been guided by the primary abilities that have been isolated in previous factorial studies. In a previous investigation[2] it was found that a test of mechanical movement had a component of inductive reasoning. This seemed plausible because in doing this test the subject must comprehend the nature of the mechanism in a purely descriptive but non-technical way. He must then trace the successive displacements that are initiated by the driver in the mechanism. For this reason we have included here several tests that have been previously identified as tests of induction.

In an experimental and factorial study of perception[3] two factors were tentatively identified in connection with perceptual closure. These were called speed of closure and flexibility of closure, respectively. It seemed plausible that perceptual closure should be involved in the comprehension of a mechanism and consequently some of our best tests for closure were included in the present battery.

In order to facilitate interpretation of the factors with special regard to mechanical aptitude we have included several measures of mechanical skill and experience. For this purpose we used tests in which the subject was asked to identify mechanical and electrical tools and some common

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[2] Ibid.

[3] L. L. Thurstone, A Factorial Study of Perception (Chicago: University of Chicago Press, 1944).

terminology for them. These were called tests of mechanical experience and electrical experience. For a similar purpose we included a Navy form of Bennett's Mechanical Comprehension Test which reflects not only the subject's command of intuitive physics but also some elementary knowledge of physics, especially the sections on elementary mechanics and applications. In addition to these measures of experience and elementary training and skill we gave all of our subjects two interest schedules. These schedules made it possible to identify those subjects who have a dominant interest in mechanical things from those who are indifferent or who even dislike mechanical things. These several experience, skill, and interest measures were used for the purpose of separating the subjects into two groups for another section of this investigation.

The following table shows a list of the thirty-six group tests that were constructed or assembled. Four of these tests were omitted from the testing program because of lack of time. Each of these four tests has been marked in the table with an asterisk. The remaining thirty-two tests were given. The table shows the initial tentative classification of the tests. It will be shown later that the factorial results do not match exactly these tentative headings because the number of factors exceeds the number of classifications in this table.

Space Tests:
- Block Counting
- Paper Puzzles
- Cards
- Figures
- Hands
- Reversals and Rotations
- Copying
- Block Assembly
- Rotation of Solid Figures

Experience Tests:
- Mechanical Comprehension I
- * Mechanical Comprehension II
- Mechanical Experience
  - *a. Verbal form
  - b. Pictorial form
- Electrical Experience
  - *a. Verbal form
  - b. Pictorial form

Movement:
- Mechanical Movements
- Surface Development
- Lozenges A
- Cubes
- Bolts

Visual Memory:
- Memory for Pictures
- Memory for Geometric Designs
- Visual Memory

Closure:
- Gottschaldt Figures
- Street Gestalt Completion
- Mutilated Words
- Designs

Perception:
- Identical Forms
- Mutilated Pictures
- Jig-Saw Pieces
- Picture Squares

Reasoning:
- Letter Grouping
- Figure Grouping
- Figure Analogies
- * Code Words
- Letter Series

Interest Analyses:
- Kuder Preference Scale
- Thurstone Interest Analysis

The Subjects and the Administration of the Tests

Thirty-two of the above tests were administered in March, 1947, to a group of 350 boys in the Tilden Technical High School, Chicago. These boys, who were juniors in high school, were all enrolled in high school physics classes, and the tests were administered during half of the laboratory periods. Ten such testing periods were used, and since the laboratory classes met twice a week, the testing occupied five weeks.

The co-operation of the Chicago Public Schools in this project is most gratefully acknowledged. Arrangements for administering the group tests were made through Dr. Grace Munson, who was then Director of the Bureau of Child Study, and Mr. George F. Cassell, Acting Superintendent of Schools. Mr. Robert Lakemacher, Principal, and Mr. Burton Duffie, who was then Assistant Principal, of the Tilden Technical High School, made the arrangements for the subjects. We are also grateful to the four instructors, Mr. Gamaertsfelder, Mr. Hotchkins, Mr. Steuber, and Mr. Stone, who were kind enough to rearrange their laboratory teaching to conform to the testing schedule.

Several examiners assisted in the testing program. The examiners were Thomas Jeffrey, James Degan, Robert Chapman, Fred Gehlmann, Katharine Vitato, Alexandra Thanos, and Thelma Gwinn Thurstone.

Before the end of the school year, about twenty-five tests had been scored and a report was sent to each boy explaining his scores on the tests. At the beginning of the testing program the boys had been promised this report, and their interest in the tests was soundly motivated. The individual tests of mechanical aptitude will be described and analyzed in a separate report.

Description of Group Tests

The thirty-two group tests that were assembled for the present study have been described in detail in a separate report, Psychometric Laboratory Report No. 54, March, 1949. The same tests have also been recorded on microfilm on file in the University of Chicago Library. Copies of this film can be obtained by ordering Negative No. 1768, Mechanical Aptitude - Complete Set of Group Tests, by Thelma Gwinn Thurstone and L. L. Thurstone. If a complete report of this study is to be published in monograph form, it is likely that the detailed test descriptions will be included.

In Table 1 we have listed the names of the thirty-two tests. For each test the table shows the code number, the reliability, the time limits for the fore-exercise and for the test proper, and the scoring formula. The reliabilities were computed by the split half method, and the coefficients are presented for what they are worth. In factor analysis the test reliabilities are not of major concern provided that the reliabilities are high enough to help in the definition of common factors. Reliability coefficients can be computed in different ways with different assumptions. A speed test which has a split half reliability coefficient of .97 can be expected to show a lower reliability if two parallel forms are given to the same subjects with a time separation. On the other hand, if a subject does the task with ease on one occasion, he will not be in the lower quartile two months later, unless he is the unusual freak case. The reliabilities of such a test would be expected to be relatively high by any method of computation. The time limits are shown separately for the fore-exercise and for the test proper. It will be seen that in some tests the fore-exercise time is much longer than the time for the test proper. We consider this practice to be defensible to insure that the subject knows pretty well what he is expected to do before he starts the test proper. The scoring formulae were adjusted by considering the kind of score that was thought to be most profitable for the purposes of this study. The scoring formulae were also adjusted in terms of the type of question and response, including the number of distractors in multiple choice forms. The tests will be identified by the same code numbers throughout this report.

A brief acknowledgement will be given here about the sources for the group tests in this battery.

The tests Block Counting and Copying were adapted and extended from the tests of MacQuarrie. The Block Counting Test has been very widely used. One of the earliest forms was in a test by Brigham. The Street Gestalt Completion Test was designed by Street. We have adapted the Street Completion Test for paper and pencil form, and also for microfilm presentation with a projector. In the latter case the individual responses are separately timed. In the present battery a paper-pencil form of the Street Test was used.

The Cubes Test is a modification of a test originally prepared by Brigham. It is the writer's recollection that the Letter Grouping Test was originally suggested by Landahl as a test of induction. The Figure Analogies Test is a familiar form that has been used for many years in the Psychological Examination of the American Council on Education. It was originally designed by Professor Lewis O. Anderson of Hibbing Junior College and Professor V. A. C. Henmon of the University of Wisconsin.

TABLE 1

Group Tests

Test	Reliability	Time Limits Fore-Exercise	Time Limits Test	Scoring Formula
1. Block Counting	.96	6 min.	10 min.	S = R
2. Paper Puzzles	.68	3 min.	9 min.	S = R - W/3
3. Cards	.95	2 min.	5 min.	S = R - W
4. Figures	.96	2 min.	5 min.	S = R - W
5. Hands	.92	4 min.	3 min.	S = R - W
6. Copying	.94	3 min.	6 min.	S = R
7. Bolts	.93	3 min.	4 min.	S = R - W
8. Gottschaldt Figures	.78	4 min.	5 min.	S = R - W
9. Street Pictures	.68	1 min.	3 min.	S = R
10. Mutilated Words	.80	2 min.	4 min.	S = R
11. Designs	.97	2 min.	4 min.	S = R
12. Memory for Pictures*	.82	5 min.	15 min.	S = R
13. Visual Memory*	.64	5 min.	20 min.	S = R - W
14. Mechanical Movements	.76	3 min.	20 min.	S = (R - W) + 20
15. Surface Development	.96	2 min.	14 min.	S = R
16. Reversals and Rotations	.94	2 min.	7 min.	S = R - W
17. Lozenges A	.96	10 min.	5 min.	S = R - W
18. Cubes	.78	9 min.	6 min.	S = R - W
19. Identical Forms	.96	3 min.	5 min.	S = R - W/4
20. Mutilated Pictures	.80	2 min.	4 min.	S = R - W
21. Jig-Saw Pieces	.84	2 min.	7 min.	S = R - W/2
22. Memory for Geometric Design*	.73	2 min.	7 min.	S = R
23. Picture Squares	.81	1 min.	4 min.	S = R
24. Letter Series	.94	4 min.	5 min.	S = R
25. Letter Grouping	.83	3 min.	5 min.	S = R - W/3
26. Figure Analogies	.82	3 min.	5 min.	S = R - W/4
27. Figure Grouping	.66	3 min.	4 min.	S = R - W/4
28. Mechanical Comprehension - Book 1	.77	4 min.	20 min.	S = R
29. Rotation of Solid Figures	.74	2 min.	3.5 min.	S = R - W/4
30. Block Assembly	.66	2 min.	11 min.	S = R - W/3
31. Mechanical Experience ¶	.86	2 min.	11 min.	S = R
32. Electrical Experience ¶	.85	2 min.	12 min.	S = R

The Thurstone Interest Schedule and the Kuder Preference Record were used in the battery but not included in the analysis of test results.

* A projector was used in the administration of these tests with each stimulus projected on the screen for a period of five seconds. Times given for fore-exercise and test proper were used only as estimates of time required since all subjects were asked to complete all items.

¶ The time limits listed for these tests were used as guides only. Enough time was allowed for each subject to complete all items in the tests.

Thelma Gwinn Thurstone designed the following tests: Paper Puzzles, Memory for Pictures, Visual Memory, Reversals and Rotations, Jig-Saw Pieces, Memory for Geometric Designs, Picture Squares, Letter Series, and Mutilated Pictures.

The writer designed the following tests: Figure Grouping which is an adaptation of one of Spearman's early tests for "g", Cards, Figures, Hands, Mutilated Words, Designs, Mechanical Movements, Surface Development, Lozenges A, Identical Forms, Bolts, and Gottschaldt Figures. The tests Hands, Mechanical Movements, and Lozenges A were designed by the writer at Carnegie Institute of Technology about 1918 as tests for visualizing. The Gottschaldt Figures were adapted for a group test of closure. We have retained Gottschaldt's name for this test because most of the figures were obtained from his publications. The Bolts Test was designed by the writer for Dr. J. H. Hazlehurst who used this test in his doctor's dissertation. The Designs Test was originally designed as a test of perception. It failed to reveal a strong perceptual speed factor. Its factorial composition remained unknown until the test was included with other tests of perceptual closure. It was then found that the unknown variance in the Designs Test was due to the closure factors which had not been isolated when this test was first constructed. The following tests have been used in previous factorial studies from the Psychometric Laboratory: Block Counting, Cards, Figures, Hands, Copying, Gottschaldt Figures, Street Pictures, Mutilated Words, Designs, Memory for Pictures, Visual Memory, Mechanical Movements, Surface Development, Lozenges A, Cubes, Identical Forms, Letter Series, Letter Grouping, Figure Analogies, and Figure Grouping.

The following Navy tests were included in essentially the same form in which these tests have been previously used in the Navy: Mechanical Comprehension, Rotation of Solid Figures, Block Assembly, Mechanical Experience, and Electrical Experience.

Factor Analysis of the Group Tests

The first step in the factor analysis of the thirty-two group tests was the computation of 496 Pearson product moment correlation coefficients. The correlation matrix is shown in Table 2.

This correlation matrix was factored by the complete centroid method[1] and the result is shown in Table 3. In this table the communalities have also been recorded. Ten orthogonal factors are represented in Table 3 and the distribution of tenth factor residuals is shown in Table 4. The correlation matrix was factored twice, using the communalities obtained from the first factoring as estimates of the diagonal entries in factoring the second time. This distribution of residuals after ten factors includes the residuals of the diagonal entries. The small tenth factor residuals indicated pretty clearly that the common factor variance is represented in the factor matrix F. Therefore, we might expect to have one or more residual factor or factors with small variance.

The rotational solution is represented in the transformation matrix Λ of Table 5. The cosines of the angular separations of the reference vectors are listed in Table 6. Inspection of these cosines indicates that some of the primary factors will have significant correlations. There are several correlations as high as .40, but most of the reference axes are practically orthogonal. Since the larger values in Table 6 are negative, we may expect the corresponding primary abilities to be positively correlated.

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1. L. L. Thurstone, Multiple Factor Analysis, A Development and Expansion of The Vectors of Mind, (Chicago: University of Chicago Press, 1947), Chapter VIII.

TABLE 2

Correlations of Thirty-two Group Tests

	Block Counting	Paper Puzzles	Cards	Figures	Hands	Copying	Bolts	Gottschaldt Figures	Street Pictures	Mutilated Words	Designs	Memory for Pictures	Visual Memory	Mechanical Movements	Surface Development	Reversals and Rotations
Test No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1		.42	.50	.37	.21	.43	.39	.47	.23	.24	.38	.32	.14	.43	.54	.41
2	.42		.37	.32	.08	.42	.24	.42	.19	.19	.31	.22	.14	.42	.58	.33
3	.50	.37		.76	.34	.39	.35	.47	.14	.18	.37	.25	.22	.37	.54	.62
4	.37	.32	.76		.33	.36	.37	.47	.18	.23	.40	.21	.17	.35	.45	.60
5	.21	.08	.34	.33		.18	.41	.16	.12	.18	.22	.05	.03	.10	.27	.25
6	.43	.42	.39	.36	.18		.28	.47	.20	.25	.45	.27	.16	.38	.50	.39
7	.39	.24	.35	.37	.41	.28		.29	.19	.23	.25	.27	.18	.37	.38	.32
8	.47	.42	.47	.47	.16	.47	.29		.27	.28	.49	.23	.23	.41	.53	.46
9	.23	.19	.14	.18	.12	.20	.19	.27		.36	.17	.17	.02	.15	.21	.20
10	.24	.19	.18	.23	.18	.25	.23	.28	.36		.25	.16	.08	.18	.20	.25
11	.38	.31	.37	.40	.22	.45	.25	.49	.17	.25		.18	.18	.26	.35	.44
12	.32	.22	.25	.21	.05	.27	.27	.23	.17	.16	.18		.25	.29	.28	.20
13	.14	.14	.22	.17	.03	.16	.18	.23	.02	.08	.18	.25		.19	.15	.07
14	.43	.42	.37	.35	.10	.38	.37	.41	.15	.18	.26	.29	.19		.56	.29
15	.54	.58	.54	.45	.27	.50	.38	.53	.21	.20	.35	.28	.15	.56		.49
16	.41	.33	.62	.60	.25	.39	.32	.46	.20	.25	.44	.20	.07	.29	.49	
17	.49	.40	.58	.57	.38	.39	.43	.48	.17	.25	.40	.27	.17	.45	.58	.55
18	.44	.39	.52	.40	.27	.31	.27	.35	.19	.15	.25	.16	.12	.34	.57	.41
19	.39	.31	.36	.36	.17	.40	.30	.34	.29	.28	.39	.31	.10	.19	.37	.39
20	.42	.28	.36	.30	.11	.33	.25	.31	.26	.25	.29	.29	.15	.25	.41	.36
21	.28	.25	.29	.32	.13	.29	.13	.25	.16	.10	.27	.18	.09	.14	.27	.28
22	.35	.21	.33	.26	.13	.37	.31	.29	.14	.24	.20	.51	.17	.30	.29	.26
23	.28	.14	.19	.21	.08	.16	.06	.23	.23	.24	.21	.19	.19	.08	.19	.25
24	.47	.37	.37	.32	.12	.44	.33	.40	.15	.36	.35	.23	.15	.39	.43	.32
25	.47	.35	.38	.35	.17	.45	.36	.45	.18	.30	.34	.20	.11	.36	.42	.33
26	.45	.31	.33	.33	.13	.43	.31	.44	.17	.22	.35	.28	.12	.33	.46	.32
27	.42	.34	.32	.34	.06	.32	.22	.36	.21	.31	.30	.22	.05	.30	.38	.35
28	.48	.48	.41	.36	.19	.42	.44	.48	.26	.23	.30	.21	.18	.63	.62	.41
29	.34	.36	.53	.54	.18	.31	.34	.37	.15	.16	.23	.25	.14	.36	.49	.46
30	.53	.44	.32	.30	.09	.39	.26	.44	.18	.20	.28	.30	.25	.40	.47	.26
31	.30	.34	.23	.22	.02	.19	.27	.26	.19	.12	.13	.18	.09	.50	.39	.16
32	.23	.32	.26	.18	.01	.22	.26	.24	.18	.13	.12	.25	.10	.49	.47	.13

TABLE 2

Correlations of Thirty-two Group Tests

	Lozenges A	Cubes	Identical Forms	Mutilated Pictures	Jig-Saw Pieces	Memory for Geometric Design	Picture Squares	Letter Series	Letter Grouping	Figure Analogies	Figure Grouping	Mechanical Comprehension Book I	Rotation of Solid Figures	Block Assembly	Mechanical Experience	Electrical Experience
Test No.	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	.49	.44	.39	.42	.28	.35	.28	.47	.47	.45	.42	.48	.34	.53	.30	.23
2	.40	.39	.31	.28	.25	.21	.14	.37	.35	.31	.34	.48	.36	.44	.34	.32
3	.58	.52	.36	.36	.29	.33	.19	.37	.38	.33	.32	.41	.53	.32	.23	.26
4	.57	.40	.36	.30	.32	.26	.21	.32	.35	.33	.34	.36	.54	.30	.22	.18
5	.38	.27	.17	.11	.13	.13	.08	.12	.17	.13	.06	.19	.18	.09	.02	.01
6	.39	.31	.40	.33	.29	.37	.16	.44	.45	.43	.32	.42	.31	.39	.19	.22
7	.43	.27	.30	.25	.13	.31	.06	.33	.36	.31	.22	.44	.34	.26	.27	.26
8	.48	.35	.34	.31	.25	.29	.23	.40	.45	.44	.36	.48	.37	.44	.26	.24
9	.17	.19	.29	.26	.16	.14	.23	.15	.18	.17	.21	.26	.15	.18	.19	.18
10	.25	.15	.28	.25	.10	.24	.24	.36	.30	.22	.31	.23	.16	.20	.12	.13
11	.40	.25	.39	.29	.27	.20	.21	.35	.34	.35	.30	.30	.23	.28	.13	.12
12	.27	.16	.31	.29	.18	.51	.19	.23	.20	.28	.22	.21	.25	.30	.18	.25
13	.17	.12	.10	.15	.09	.17	.19	.15	.11	.12	.05	.18	.14	.25	.09	.10
14	.45	.34	.19	.25	.14	.30	.08	.39	.36	.33	.30	.63	.36	.40	.50	.49
15	.58	.57	.37	.41	.27	.29	.19	.43	.42	.46	.38	.62	.49	.47	.39	.47
16	.55	.41	.39	.36	.28	.26	.25	.32	.33	.32	.35	.41	.46	.26	.16	.13
17		.55	.37	.34	.26	.27	.25	.42	.43	.46	.30	.49	.47	.37	.27	.26
18	.55		.31	.32	.25	.15	.25	.41	.33	.36	.28	.43	.43	.32	.30	.29
19	.37	.31		.39	.30	.22	.34	.38	.40	.39	.41	.35	.26	.28	.17	.16
20	.34	.32	.39		.12	.22	.30	.37	.34	.32	.25	.30	.28	.33	.21	.24
21	.26	.25	.30	.12		.10	.19	.21	.20	.20	.25	.16	.31	.26	.10	.09
22	.27	.15	.22	.22	.10		.16	.25	.28	.30	.25	.26	.24	.25	.16	.24
23	.25	.25	.34	.30	.19	.16		.27	.26	.22	.21	.12	.18	.22	.06	.00
24	.42	.41	.38	.37	.21	.25	.27		.68	.54	.38	.40	.31	.42	.05	.16
25	.43	.33	.40	.34	.20	.28	.26	.68		.54	.42	.41	.37	.41	.06	.20
26	.46	.36	.39	.32	.20	.30	.22	.54	.54		.34	.36	.27	.35	.14	.27
27	.30	.28	.41	.25	.25	.25	.21	.38	.42	.34		.38	.27	.32	.19	.18
28	.49	.43	.35	.30	.16	.26	.12	.40	.41	.36	.38		.36	.45	.51	.57
29	.47	.43	.26	.28	.31	.24	.18	.31	.37	.27	.27	.36		.45	.31	.28
30	.37	.32	.28	.33	.26	.25	.22	.42	.41	.35	.32	.45	.45		.29	.26
31	.27	.30	.17	.21	.10	.16	.06	.05	.06	.14	.19	.51	.31	.29		.55
32	.26	.29	.16	.24	.09	.24	.00	.16	.20	.27	.18	.57	.28	.26	.55	

TABLE 3

Centroid Factor Matrix F

Test	I	II	III	IV	V	VI	VII	VIII	IX	X	h^2
1	.70	.09	-.04	.10	.06	-.04	-.10	.01	-.09	-.03	.53
2	.59	-.06	-.14	.22	.16	-.14	.05	.04	.03	-.04	.47
3	.70	-.25	.28	-.08	-.19	-.22	.03	-.12	.03	.03	.74
4	.66	-.23	.39	-.13	-.23	-.10	.17	-.12	.11	-.10	.79
5	.32	-.20	.26	-.12	-.18	.15	-.14	.31	-.18	-.11	.44
6	.63	.16	-.07	.14	-.10	-.06	.17	.06	-.09	-.05	.50
7	.54	-.15	-.06	-.20	-.21	.31	-.11	.16	-.09	-.19	.58
8	.67	.08	.02	.14	-.07	-.08	.17	.12	.13	.05	.55
9	.35	.14	.08	-.21	.31	.11	.11	.11	.05	.03	.33
10	.41	.23	.14	-.17	.10	.28	.13	.06	.10	.07	.39
11	.54	.16	.14	.11	-.11	-.04	.22	.22	-.02	-.02	.46
12	.45	.21	-.28	-.35	-.13	-.15	-.04	-.10	-.17	.09	.54
13	.26	.07	-.12	-.12	-.15	-.17	-.07	.11	.22	.06	.22
14	.62	-.23	-.36	.09	-.04	.09	.06	-.04	.11	.03	.60
15	.77	-.23	-.11	.18	.08	-.08	-.05	.05	-.04	.07	.71
16	.63	-.11	.36	.02	-.06	-.13	.15	.03	-.07	.12	.60
17	.72	-.20	.17	.06	-.14	.02	-.13	.06	-.07	.09	.64
18	.61	-.22	.15	.10	.15	-.05	-.25	-.07	-.06	.13	.57
19	.57	.24	.15	-.07	.14	.04	.04	.01	-.17	-.03	.46
20	.53	.14	.02	-.13	.12	-.05	-.14	.10	.05	.10	.38
21	.38	.05	.14	.03	.04	-.16	.04	-.04	-.11	-.20	.25
22	.46	.15	-.24	-.26	-.27	-.05	.07	-.06	-.14	.10	.47
23	.36	.30	.19	-.13	.16	-.07	-.14	.02	.05	.10	.34
24	.63	.29	.04	.27	-.09	.23	-.19	-.16	.13	.02	.70
25	.63	.26	.06	.22	-.14	.25	-.10	-.15	.11	-.06	.65
26	.60	.19	-.03	.17	-.11	.14	-.08	-.10	-.10	.08	.49
27	.53	.16	.04	.09	.14	.06	.16	-.13	-.08	-.08	.39
28	.70	-.26	-.25	.11	.15	.21	.11	.12	.09	.04	.74
29	.60	-.22	.11	-.04	-.03	-.16	-.08	-.19	.10	-.16	.53
30	.60	.11	-.21	.10	.06	-.19	-.16	.05	.19	-.23	.58
31	.43	-.36	-.35	-.13	.31	.00	.13	-.01	.08	-.03	.57
32	.45	-.30	-.41	-.10	.19	.13	.09	-.17	.05	.11	.58

TABLE 4

Distribution of Tenth Factor Residuals

Residual	Frequency
-.06	8
-.05	18
-.04	37
-.03	71
-.02	123
-.01	177
.00	192
.01	145
.02	113
.03	73
.04	43
.05	18
.06	4
.07	2
	1024

TABLE 5

Transformation Matrix Λ

	A	B	C	D	E	F	G	H	J	K
I	.128	.253	.142	.142	.144	.098	.166	.187	.140	.116
II	.129	-.469	-.386	.279	-.189	-.193	.267	.085	.221	.145
III	-.066	-.527	.500	-.352	.298	.050	-.348	-.071	.209	-.042
IV	.266	-.014	-.253	-.327	.069	-.211	-.166	.510	-.458	-.148
V	-.265	.530	-.166	-.204	.274	-.207	-.136	.106	.678	.443
VI	.696	.202	-.220	-.145	-.132	.452	-.600	-.282	.283	-.310
VII	-.174	.090	.178	.199	-.604	-.187	-.206	.520	.220	-.180
VIII	-.466	.133	-.555	-.370	.109	.643	.433	.417	.133	-.193
IX	.299	.287	.320	-.653	-.387	-.159	.380	-.396	.202	-.110
X	-.028	-.088	.000	.077	.480	-.431	.000	-.006	.176	-.754

TABLE 6

Reference Vector Cosines C

	A	B	C	D	E	F	G	H	J	K
A	1.000									
B	.014	1.000								
C	.082	-.141	1.001							
D	-.116	-.268	-.083	1.000						
E	-.247	-.108	-.083	-.067	.999					
F	-.005	.134	-.339	-.216	-.028	1.000				
G	-.399	.057	-.212	-.060	-.075	-.004	1.000			
H	-.452	.026	-.392	.135	-.027	-.022	.072	.999		
J	-.117	.325	.010	-.145	.045	.002	-.087	-.123	1.000	
K	-.227	.151	.011	.124	-.103	.033	.135	-.030	.100	1.001

The oblique factor matrix V, which is the principal objective of the factorial computations, is shown in Table 7. Since this is the table to be used in the interpretation of the factors, the names of the tests and the communalities are also shown here. During the computational work these oblique factors were identified by the letters A to K, but in Table 7 the columns are denoted by letters which refer to our psychological interpretation of the factors. In the interpretation we have considered factor loadings of .30 and higher to be sufficiently high to be significant, and in general we have ignored factor loadings below .30. For convenience in analyzing the psychological nature of the factors, factor loadings which are .30 or higher can be underlined; then as each column is examined in relation to the names of the tests and the communalities, the underlined values are those which must be consistent with the psychological interpretation.

Our present interpretation of the factorial results indicates each primary factor which can be given psychological interpretation and one residual factor. The primary factors in the common variance of these thirty-two tests seem to be induction I; three space factors, S_1, S_2, and S_3; two memory factors, M_2 and M_3; kinesthetic imagery K; and two closure factors, C_1 and C_2. These primary factors will be discussed separately for each column of the oblique factor matrix.

The first column of the oblique factor matrix V has small entries except in three tests, namely, Letter Series, Letter Grouping, and Figure Analogies. All three of these tests have previously been interpreted as tests of the inductive factor I.[1] Among the small entries we find that Mechanical Movements has a low saturation of .21 on the inductive factor. The Bolts Test has a saturation of .20. The test in Mechanical Movements has been found in previous studies to have a low saturation on the inductive factor.[2]

The space factor S_1 has high saturations for the two tests Cards (.52) and Figures (.60). These tests have consistently appeared as the best measures of this space factor in previous studies. Significant saturations are also found for Reversals and Rotations (.33) and Rotation of Solid Figures (.40). The interpretation of this factor is that it represents the ability to visualize a rigid configuration when it is moved into different positions. Among the low saturations we notice Lozenges A (.19) and Cubes (.18). These two tests also require the subject to visualize a rigid structure that is moved from one position to another, but the first space factor is not dominant in these two tests.

The second space factor is represented very strongly in the criteria measures Mechanical Experience (.66), Electrical Experience (.59), and Mechanical Comprehension (.60). All three of these measures represent mechanical experience. The Mechanical Comprehension Test may be regarded as determined partly by mechanical experience, partly by elementary training in physics, and partly by the intuitive comprehension of mechanical problems. In this sense it could be defined either as a part of the criterion as we have used it here, or as a test which includes a considerable saturation of experience. It is conceivable that the items of this test could be separated into two groups. An item analysis of this test with appropriate additional measures would probably indicate these different sources of variance. Among the tests we find three appreciable loadings, namely, Surface Development (.37), Mechanical Movements (.48), and Paper Puzzles (.33). A somewhat lower saturation in this second space factor is found in Block Assembly (.27). Since this space factor has the highest saturation in the three criterion measures for this battery, the interpretation of this space factor is of central importance for the present problem. Our interpretation is that the space factor S_2 represents the ability to visualize a configuration in which there is movement or displacement among the parts of the configuration. In this sense it differs from the first space factor S_1 which seems to represent the ability to visualize a rigid configuration as it is moved from one position to another. In Mechanical Movements the configuration consists of the several parts of a mechanism that is represented in a pictorial manner. The configuration that the subject thinks about evidently

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1. L. L. Thurstone and Thelma Gwinn Thurstone, Psychometric Monographs Number 2, Factorial Studies of Intelligence (Chicago: University of Chicago Press, 1941).

2. L. L. Thurstone, Psychometric Monograph Number 1, Primary Mental Abilities (Chicago: University of Chicago Press, 1938).

TABLE 7

Oblique Factor Matrix V

	I	S_1	S_2	S_3	K	M_2	M_3	C_1	C_2	Res.	h^2
1. Block Counting	.07	-.03	.15	.18	.05	.13	.14	.05	.20	.17	.53
2. Paper Puzzles	-.02	-.02	.33	.08	-.05	.00	.18	.02	.32	.16	.47
3. Cards	-.03	.52	.00	.18	-.01	.06	.08	-.05	.04	.02	.74
4. Figures	.05	.60	-.03	-.01	.08	.00	-.02	.02	.01	.03	.79
5. Hands	-.05	.02	-.04	.22	.52	-.08	-.04	-.02	.03	-.04	.44
6. Copying	.04	-.04	.06	-.06	.03	.21	.16	-.02	.36	.06	.50
7. Bolts	.20	-.02	.20	.00	.52	.08	.00	.01	-.07	.03	.58
8. Gottschaldt Figures	.05	.07	.13	-.03	.00	.00	.23	.07	.30	-.04	.55
9. Street Pictures	-.06	-.01	.21	.04	.07	.00	.04	.49	.05	.12	.33
10. Mutilated Words	.17	.03	.08	-.04	.11	.01	-.04	.43	-.02	-.04	.39
11. Designs	-.04	.00	-.04	-.04	.12	.04	.15	.07	.38	-.04	.46
12. Memory for Pictures	-.06	-.02	.00	.02	-.05	.53	.29	.04	-.02	.11	.54
13. Visual Memory	-.04	.04	.05	-.04	.01	.00	.39	-.01	-.04	-.03	.22
14. Mechanical Movements	.21	.03	.48	-.06	.05	.07	.12	-.05	.11	-.04	.60
15. Surface Development	.02	.05	.37	.25	.04	.02	.13	-.02	.26	.04	.71
16. Reversals and Rotations	-.09	.33	-.05	.22	.00	.03	-.01	.10	.24	-.06	.60
17. Lozenges A	.09	.19	.08	.31	.18	.00	.03	-.04	.10	-.08	.64
18. Cubes	.05	.18	.19	.46	-.01	-.06	-.02	.06	.03	.07	.57
19. Identical Forms	.00	.00	.00	.14	.06	.20	.01	.27	.18	.19	.46
20. Mutilated Pictures	-.03	-.01	.12	.21	.04	.04	.24	.25	.02	.09	.38
21. Jig-Saw Pieces	-.08	.12	-.03	.04	.02	.10	.05	.01	.18	.27	.25
22. Memory for Geometric Design	.03	.01	-.03	-.07	.02	.47	.22	-.03	.04	-.04	.47
23. Picture Squares	-.03	.03	-.08	.21	-.06	.03	.17	.30	-.04	.13	.34
24. Letter Series	.52	-.01	-.01	.07	-.02	-.01	.02	.01	-.01	.00	.70
25. Letter Grouping	.50	.03	-.01	-.02	.04	.02	-.02	.00	.00	.02	.65
26. Figure Analogies	.30	-.05	-.01	.12	.00	.19	.00	-.03	.12	-.03	.49
27. Figure Grouping	.13	.05	.10	-.02	-.06	.16	-.07	.18	.22	.18	.39
28. Mechanical Comprehension Book I	.16	-.04	.60	.03	.17	-.06	.03	.16	.21	-.04	.74
29. Rotation of Solid Figures	.06	.40	.16	.08	.00	.00	.08	-.04	-.05	.24	.53
30. Block Assembly	.05	-.05	.27	-.03	.04	-.02	.42	-.02	.11	.34	.58
31. Mechanical Experience	-.08	.06	.66	-.02	.03	.04	.08	.22	.07	.16	.57
32. Electrical Experience	.14	.07	.59	-.01	-.06	.16	-.02	.15	-.02	.01	.58

has movement among its parts. The same characteristic applies to Surface Development, where the subject thinks about the flat form that can be considered to be a piece of cardboard or sheet metal. The subject must imagine that the cardboard is folded along the dotted lines into a form that is like the solid figure. This test evidently involves a configuration in which there is displacement and deformation among the parts. In Paper Puzzles the configuration consists of a group of flat pieces which are moved among themselves so as to fit a required outline. The subject shows that he has thought of the problem to a correct solution by indicating which of the pieces will be left over. This characteristic of the second space factor is obviously conspicuous in the criterion measures of Mechanical Experience, Electrical Experience, and Mechanical Comprehension. It looks as if we might conclude that an essential characteristic of mechanical aptitude is the ability to keep in mind a configuration in which there is internal movement and displacement, or even deformation among the parts. Stated in more general psychological terms, we might say that mechanical aptitude is represented by the ability to visualize a flexible configuration. The description of mechanical aptitude in this manner seems after all rather obvious, but it was not at all obvious at the start of this investigation when a number of psychological hypotheses were entertained. For example, the visualizing of movement as such does not seem to be a factor because the visualizing of movement is involved in both space factors S_1 and S_2. The difference between these two factors is that in one case it is the visualizing of a rigid figure that is moved from one position to another, whereas in the second factor the configuration that one is thinking about has internal movement among its parts. Consequently, we cannot say that the second space factor was represented by any of our hypotheses. Even though this space factor seems fairly simple to interpret in the factor matrix V, it was not represented as one of our hypotheses.

The third space factor S_3 is represented in this battery by only two tests, namely, Lozenges A (.31) and Cubes (.46). All of the other saturations in this factor are low. Hence an interpretation of the factor that is common to Lozenges A and Cubes will not be attempted.

In previous factorial studies a memory factor has been identified in connection with the ability to learn paired associates. It has been suspected that incidental memory is quite different from the ability to memorize. Incidental memory seems to differ from memorizing ability in that incidental memory is the ability to recall past experience which one did not intend to memorize. The memory factor M_1 seems to represent the ability to memorize intentionally. In the memory factor M_2 we have high saturations in two tests, namely Memory for Pictures (.53) and Memory for Geometric Designs (.47). In both of these tests the subject was shown a long series of pictures or of geometric designs. These were shown on a screen with a projector, one at a time. At the end of this presentation the subject was given a booklet in which he was asked to identify exactly which pictures he had seen, or exactly which geometric designs he had seen. In each of these recall items he was given sets of four pictures or designs which were similar. The subject was asked to show precisely which one he had seen on the screen. Both of these tests were arranged in such a way as to suppress as far as possible the effect of verbalizing. If there was a picture of a hat in the series of projected pictures, then the recall item would consist of four pictures of hats. The subject was asked to designate which one had been shown on the screen. In this way the subject was not able to gain appreciably in recall by merely verbalizing the pictures or designs. Even if the subject did gain something in this manner, the gain from verbalization was undoubtedly relatively slight.

An interesting item in the interpretation of the second memory factor M_2 is that the test Visual Memory has .00 projection on this factor. If one pays attention only to the names of the tests this seems a bit startling, but the apparent inconsistency is immediately resolved as soon as one looks at the actual tests. In the test called Visual Memory the subject was shown an irregular figure on the screen for a few seconds. Immediately afterwards there was another figure very similar to the first one, and the subject was asked to specify immediately whether the present figure was exactly like the previous one. The figures differed in some detail of the outline. The intention of this test was to ascertain whether the subject had the ability to keep in mind for immediate recall the exact shape of an irregular outline. In no case was there any gross difference between the two outlines except in the instructional items. Here the subject's ability to produce a correct response was not memory and recall in the ordinary sense. It depended on his degree of accuracy of perception of a single figure and its comparison with the next figure. Previous studies in perception have indicated the existence of a perceptual factor that is concerned with the ability to discover minute details and high accuracy of comparison of lengths and angles. It may be that this test represents such an ability. It does not represent sustained memory in the usual sense.

The third memory factor M_3 has significant saturations on several tests, namely, Block Assembly (.42), Visual Memory (.39), Memory for Pictures (.29), Mutilated Pictures (.25), and possibly Gottschaldt Figures (.23). This factor seems to represent the ability to keep in mind some perceptual detail, as contrasted with the sustained memory that is required in the second memory factor.

The factor K has only two tests with significant loadings, namely, Hands (.52) and Bolts (.52). There is no other appreciable saturation in this factor. Our tentative interpretation is that this factor represents kinesthetic imagery, and the factor is therefore given the tentative notation K. In both the Hands and the Bolts tests the subject undoubtedly has some kinesthesis. This is especially evident in watching a group of subjects take the Hands Test. Some subjects find this test extremely easy so that they can make the discriminations as fast as they can mark the paper. A large proportion of any normal group of subjects will find some difficulty with this test. Those subjects can be seen holding up their right hand and then their left hand to see if they can twist the hand into the position of the picture. That contortion is a part of the effort to decide whether each particular picture represents a right hand or a left hand. It is sometimes an amusing performance. One can hardly doubt the kinesthetic imagery with these subjects and especially, of course, with those who try to make these judgements without twisting their own hands into the position shown in the pictures. Because of the fact that there are only two tests with high saturations in this factor, our interpretation must be tentative. Among the other tests there is no case in which one would definitely expect kinesthetic imagery in addition to the space factors that have been discussed. The further identification of the factor that has here been tentatively denoted as kinesthetic imagery K must await further experimentation with more diversified test material.

The first closure factor C_1 is evidently the same factor which has been called speed of closure in previous studies.[1] The two tests which are highest in this factor in the present battery are the Street Test with a loading of .49 and Mutilated Words with a loading of .43. These are the same two tests which have identified the speed of closure factor in previous studies. The next highest saturation in this factor is that of Picture Squares (.30). Among the lower but possibly significant saturations on the first closure factor we find Identical Forms (.27), Mutilated Pictures (.25), and Mechanical Experience (.22). The psychological characteristic of the closure factor C_1 seems to be ability to fuse a perceptual field into a single percept. The highest saturations are in those tests in which the elements are apparently disparate in the presentation and in which the subject must unify them into a single percept. In the tests with lower saturations we also have the task of formulating a closure which is more highly structured as in Identical Forms, Mutilated Pictures, and Picture Squares. Insofar as we can generalize from these few examples of the first closure factor, one may venture to guess that the first closure factor is best represented by those tests in which the presented perceptual field has no initial organization and in which the subject is asked to unify the field without any previous structuring.

It is of special interest to note that the first closure factor has a slight saturation in Mechanical Experience. It is not surprizing to find perceptual closure as a part of the variance in mechanical experience. It might even seem surprizing that perceptual closure does not play a more prominent role in the total variance of mechanical experience which is assumed to be highly correlated with mechanical aptitude.

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1. L. L. Thurstone, A Factorial Study of Perception, (Chicago: University of Chicago Press 1944).

The second closure factor C_2 has also been identified in previous studies where it was tentatively named flexibility of closure.[1] Here, as previously, this factor is significantly represented by the Gottschaldt Figures (.30), but in the present battery there are three tests with higher saturations, namely, Copying (.36), Designs (.38), and Paper Puzzles (.32).

The Designs Test was first used in a study of the perceptual speed factor P before either of the closure factors had been found. The result indicated that the Designs Test was not primarily a test of speed of perception P, and that it contained therefore a significant saturation on some additional perceptual factor. When the second closure factor C_2 was found the test battery did not contain the Designs Test, but it was predicted at that time that this test should have a saturation in the second closure factor. The present test battery is the first battery which includes the Designs Test that has been studied after the second closure factor C_2 was identified. It is therefore gratifying to find the Designs Test represented with the second closure factor, which was expected. The psychological characteristic of this closure factor seems to be the ability to keep in mind a configuration against distraction. In the best tests of this factor the subject is given the configuration that he is to keep in mind in spite of the distractions of the problem. In the Gottschaldt Figures Test he is shown a figure which is imbedded in a more complex drawing. He is expected to find that figure as a part of the larger and more complex drawing. To the extent that the larger drawing, the Gottschaldt figure, is well structured so that it has a good configuration of its own, the task of keeping in mind the original figure becomes more difficult. In the Copying Test we have the same psychological characteristic. The subject must keep in mind the angular figure which is to be reproduced against the distracting background of regularly spaced dots. In the Designs Test the subject must hold in mind the shape of the capital letter Sigma to see whether it is a part of a more complex drawing. In the Paper Puzzles Test he must keep in mind the final shape that the pieces must fit when they are assembled.

Several of the tests have smaller saturations that might be sufficiently high to justify inspection and possible interpretation. Among these we find Surface Development with a loading of .26. The subject starts with a flat configuration which must be folded into the shape of a given picture. This aspect of the task fits the description of the second closure factor. In Reversals and Rotations (.24) there is some difficulty in keeping in mind each figure because many of these figures deviate only slightly from vertical symmetry. It would be interesting to determine whether the saturation of this test on the second closure factor could be controlled in part by the degree of symmetry in the figures. The nearly symmetric figures should lead to a higher saturation in the second closure factor. The strongly non-symmetric figures in Reversals and Rotations should require less of this closure factor.

A comparison of these two closure factors seems to indicate that the first closure factor C_1 is concerned with the ability to fuse a perceptual field into a single percept. The factor is best represented when the presented field seems to be entirely unstructured. The second closure factor C_2 is concerned with the ability to keep in mind a configuration in a distracting field. The factor C_2 was called flexibility of closure when it was first identified. While it requires flexibility to maintain the figure against distraction, it might be even more appropriate to describe this factor as strength of closure. In a sense it is the strength of a closure that determines how well it can be retained in a distracting field. The first closure factor C_1 seems to facilitate the making of a closure in an unorganized field, the second closure factor C_2 seems to facilitate the retention of a figure in a distracting field. If this further interpretation of the two closure factors has any generality beyond the perceptual domain, then one could imagine that the factor C_1 determines the ease with which the subject can unify a complex situation, whereas the second factor determines the ease with which he can keep in mind its essential features against distraction. It is not to be expected that the first closure factor contributes significantly to the identification of creative talent, but it may possibly turn out to be an aspect of it. The first closure factor might be associated with inductive thinking, whereas the second closure factor might be more associated with deductive thinking. The further exploration of these two closure factors and other closely related factors may prove to be psychologically fruitful.

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1. L. L. Thurstone, A Factorial Study of Perception, (Chicago: University of Chicago Press 1944).

The analysis of the present battery of thirty-two group tests has nine factors that seem to lend themselves fairly well to psychological interpretation, and one residual factor that is left without interpretation. In terms of the major objectives of this study the most significant finding here is the second space factor. It has a very strong saturation on the criterion measures Mechanical Experience and Electrical Experience, as well as on the Mechanical Comprehension Test which can be regarded either as a criterion measure or as a test with heavy saturation in experience. The clear separation of the second space factor from the previously identified space factor S_1 can be regarded as the major finding of this analysis in relation to our major objective of isolating the primary abilities in the complex of mechanical aptitude. Of related psychological interest is the further evidence obtained here on the correlation between the two closure factors C_1 and C_2. The findings reported here for the battery of group tests will be related to a similar analysis for a battery of individual tests, and also to a battery of mixed group tests and individual tests. Finally the factors here identified will be compared for two groups of subjects who differ markedly in mechanical interests.

In analyzing further the domain of mechanical aptitude as defined by the present group tests, it is useful to have the information which has been assembled in several additional matrices. First we have the correlations between the primary factors in Table 8. It will be seen that all but one or two of the correlations are positive or zero. We have fairly high positive correlations between primary factors, but all of them, of course, are linearly independent. The values of the diagonal matrix D are listed in Table 9. These diagonal values are used in computing the matrix T of Table 10. Each row of this matrix gives the ten direction cosines of a primary vector.

Finally, we have in Table 11 the correlation between each primary factor and each of the group tests. Because of the obliqueness of the primary factors the simple structure is not directly evident in Table 11 as it is in Table 7. It is, however, of some interest to have the correlations between the primary factors and the individual tests, especially when the tests are to be assembled for predictive purposes.

Variable 28, Mechanical Comprehension, has been used here as a part of the criterion. Inspecting row 28 of Table 11 we find that Mechanical Comprehension has a correlation of .56 with the second space factor S_2, a correlation of .50 with the second closure factor C_2, and a correlation of .48 with induction I. More or less similar correlations are found in row 14 for Mechanical Movements, which is a shorter test. Here also we find that the second space factor has the highest correlation followed by significant correlations for the second closure factor and for induction. The first space factor has a significant correlation with both of the tests, Mechanical Movements and Mechanical Comprehension.

TABLE 8

Correlations between Primary Factors, R_{pq}.

	I	S_1	S_2	S_3	K	M_2	M_3	C_1	C_2	Res.
I		.38	-.08	.46	.23	.20	.56	.32	.63	.25
S_1	.38		.11	.31	.46	.27	.41	.16	.53	.02
S_2	-.08	.11		.10	-.03	.25	-.04	-.31	-.08	-.17
S_3	.46	.31	.10		.19	.20	.33	.09	.33	.16
K	.23	.46	-.03	.19		.30	.24	.14	.27	-.02
M_2	.20	.27	.25	.20	.30		.23	.13	.09	-.14
M_3	.56	.41	-.04	.33	.24	.23		.27	.38	.01
C_1	.32	.16	-.31	.09	.14	.13	.27		.29	.00
C_2	.63	.53	-.08	.33	.27	.09	.38	.29		.17
Res.	.25	.02	-.17	.16	-.02	-.14	.01	.00	.17	

TABLE 9

Diagonal Entries of D_{tp}.

	I	S_1	S_2	S_3	K	M_2	M_3	C_1	C_2	Res.
d	.641	.740	.877	.860	.857	.872	.780	.875	.697	.922

TABLE 10

Direction Cosines of Primary Vectors, $T = D\Lambda^{-1}$.

	I	II	III	IV	V	VI	VII	VIII	IX	X
I	.757	.345	.040	.321	-.140	.304	-.164	-.195	.164	-.027
S_1	.702	-.343	.402	-.159	-.253	-.192	.214	-.174	.151	-.049
S_2	.246	-.668	-.628	-.021	.271	.065	.055	-.070	.084	.072
S_3	.593	-.121	.217	.144	.166	-.072	-.586	-.007	-.279	.336
K	.466	-.199	.209	-.327	-.371	.313	-.056	.451	-.198	-.335
M_2	.471	.081	-.383	-.474	-.230	.037	.127	-.252	-.491	.157
M_3	.657	.331	-.142	-.108	-.261	-.319	-.205	.222	.392	.106
C_1	.354	.518	.330	-.[illegible]5	.383	.261	.254	.144	.148	.205
C_2	.723	.137	.225	.477	-.010	-.076	.364	.162	-.111	-.057
Res.	.180	.238	.131	.138	.384	-.197	-.289	-.256	-.105	-.726

TABLE 11

Correlations between Tests and Primary Factors, $R_{jp} = FT'$.

	I	S_1	S_2	S_3	K	M_2	M_3	C_1	C_2	Res.
1	.571	.386	.133	.496	.270	.314	.466	.214	.536	.244
2	.416	.340	.302	.344	.105	.156	.373	.091	.524	.194
3	.411	.823	.114	.464	.390	.300	.448	.111	.502	.060
4	.412	.876	.025	.291	.479	.236	.379	.198	.517	.071
5	.152	.328	-.040	.306	.616	.114	.135	.069	.221	-.011
6	.517	.389	.052	.255	.272	.334	.445	.206	.618	.116
7	.391	.376	.200	.264	.669	.380	.294	.110	.246	.023
8	.535	.494	.087	.286	.258	.197	.541	.276	.637	.021
9	.207	.174	.043	.152	.164	.144	.196	.504	.229	.088
10	.393	.242	-.076	.137	.257	.189	.262	.555	.298	-.008
11	.426	.405	-.103	.200	.339	.165	.411	.308	.620	.031
12	.258	.227	.106	.221	.186	.644	.453	.183	.120	.015
13	.171	.196	.055	.089	.114	.124	.449	.074	.092	-.068
14	.453	.383	.543	.262	.220	.350	.379	-.011	.374	-.051
15	.511	.513	.420	.569	.278	.291	.444	.064	.582	.096
16	.383	.672	-.014	.439	.345	.214	.343	.277	.602	.009
17	.523	.611	.155	.598	.467	.279	.428	.121	.525	.019
18	.429	.463	.234	.671	.206	.164	.299	.104	.392	.160
19	.455	.329	-.087	.366	.279	.314	.315	.446	.478	.241
20	.386	.287	.053	.407	.215	.234	.471	.354	.301	.106
21	.254	.330	-.047	.212	.190	.138	.202	.116	.371	.305
22	.304	.294	.096	.156	.267	.613	.428	.149	.207	-.105
23	.323	.189	-.187	.333	.082	.112	.367	.431	.227	.176
24	.831	.300	-.066	.437	.167	.162	.482	.265	.506	.213
25	.801	.354	-.073	.354	.249	.194	.448	.266	.522	.210
26	.645	.299	.015	.425	.217	.336	.391	.200	.486	.104
27	.474	.321	.044	.238	.136	.254	.229	.314	.502	.247
28	.481	.399	.563	.341	.317	.271	.335	.169	.496	-.038
29	.396	.624	.214	.374	.273	.206	.365	.030	.360	.262
30	.504	.301	.195	.298	.170	.141	.589	.084	.405	.361
31	.097	.270	.665	.147	.109	.273	.145	.054	.156	.025
32	.225	.248	.660	.193	.058	.400	.149	.040	.126	-.078

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